PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :
G02F 1/1335, G09F 9/35

A1

(11) International Publication Number: **WO 97/44703**

(43) International Publication Date: 27 November 1997 (27.11.97)

(21) International Application Number: PCT/IB97/00470

(22) International Filing Date: 30 April 1997 (30.04.97)

(30) Priority Data:
96201394.2 17 May 1996 (17.05.96) EP
(34) Countries for which the regional or international application was filed: NL et al.
96202717.3 30 September 1996 (30.09.96) EP
(34) Countries for which the regional or international application was filed: NL et al.

(71) Applicant: PHILIPS ELECTRONICS N.V. [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(71) Applicant *(for SE only)*: PHILIPS NORDEN AB [SE/SE]; Kottbygatan 7, Kista, S-164 85 Stockholm (SE).

(72) Inventors: VAN DE WITTE, Peter; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL). VAN HAAREN, Johannes, Albertus, Matthijs, Maria; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL). BROER, Dirk, Jan; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL). STALLINGA, Sjoerd; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).

(74) Agent: RAAP, Adriaan, Y.; Internationaal Octrooibureau B.V., P.O. Box 220, NL-5600 AE Eindhoven (NL).

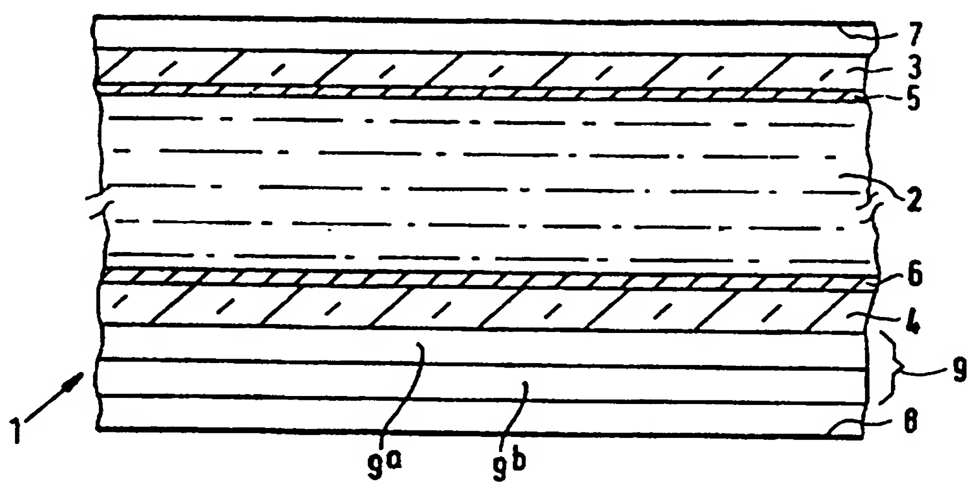
(81) Designated States: JP, KR, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: LIQUID-CRYSTAL DISPLAY DEVICE AND OPTICAL COMPONENT COMPRISING A POLARIZER

(57) Abstract

Between polarizers crossing each other at right angles, complete extinction is attained by providing one or both polarizers (8, 9) in a twisted nematic, liquid-crystalline display cell with retardation foils (9^a, 9^b) which each have an optical axis which extends in one of the planes of polarization and is tilted relative to the associated plane of the substrate. In addition, a reduction of the angle-dependence and an improved grey-scale inversion are achieved in the display device. For the retardation foils use is preferably made of a polymerized or vitrified crystalline material.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

Liquid-crystal display device and optical component comprising a polarizer.

The invention relates to a liquid-crystal display device having a display cell which comprises a layer of a nematic, liquid-crystalline material between two substantially parallel substrates, and a first and a second polarizer, which display cell is provided with a retardation foil an optical main axis of which is tilted relative to the normal to one of a plane of one of the substrates. The invention further relates to an optical component which comprises a polarizer for use, for example, in liquid-crystal display devices.

A tilted optical main axis is to be understood to mean in this context that the optical main axis makes an angle α, where $0° < \alpha < 90°$, with the normal to the surface of the (plane of the) substrate (support).

A retardation foil is to be understood to mean in this context a layer which may or may not be self-supporting and which is made of a birefringent material, or a layer having an optically compensating or delaying effect (an optically anisotropic layer). In the case of birefringence, the refractive index varies as a function of the direction of the vector of the electric field, which direction is associated with a light ray. Birefringent material has only one axis for which applies that a light ray whose vector of the electric field extends along said axis is refracted with an extraordinary refractive index n_e. Said axis is also referred to as the optical main axis of the material. In the case of light rays whose vector of the electric field extends perpendicularly to this axis, the refractive index may be the same in all directions (ordinary refractive index n_o). If, at right angles to this axis, the refractive index varies then the material is referred to as biaxial material. In this application, "the optical main axis of a layer (foil)" is to be understood to mean the average optical main axis across the thickness of the layer (the foil). Dependent upon the type of material and the structure of the layer, the optical main axis of the material may vary, for example, only in a plane at right angles to the layer. The variation occurs, for example, in the angle which the optical main axis makes with the plane of the layer, so that the effective refractive index varies across the thickness of said layer. Viewed at right angles to the layer, it is also possible, however, that the direction of the optical main axis varies in the plane of the layer. In the former case, complete extinction can be brought about between polarizers crossing

each other at 90 degrees; in the latter case, there is always some residual transmission. If the layer is provided on a (transparent) support, this support is, for example, optically isotropic.

The display devices are generally used, for example, in monitors, TV applications and, for example, display devices in motorcars and for measuring instruments. The optical components can also be used, for example, in "polarizing beam splitters" or in laser-optical systems for optical recording.

A display device of the type mentioned in the opening paragraph is described in PCT application WO 96/06380 (PHN 15.171 or US Appln. No. 8,516,904). In said Application a description is given of a display cell comprising a foil consisting of an optically anisotropic layer of a cholesterically ordered polymeric material, which serves to counteract grey-scale inversion in a twisted nematic display device. The polymeric material is ordered in such a manner that a molecular helix can be distinguished, the axis of the helix (and hence the optical main axis of the optically anisotropic layer) making an angle with a surface and the normal to one of the planes of the substrate.

After passing through the anisotropic layer, light polarized in a first direction by the first polarizer may still comprise components which are polarized in a direction at right angles to said first direction (so-called stray components). To reduce the number of stray components, the pitch of said helix is chosen to be as small as possible.

However, stray components still occur in such a display device, so that exiting light (in the case of crossed polarizers and a sufficiently high voltage across the liquid-crystal layer) is not completely extinguished.

It is an object of the invention to obviate said disadvantage as much as possible. Another object of the invention is to provide an optical component comprising a polarizer, which can suitably be used, inter alia, in such display devices.

Therefore, a liquid-crystal display device in accordance with the invention is characterized in that the optical main axis extends in a plane of polarization of the first polarizer, and the display cell is provided with a second retardation foil with an optical main axis which is tilted relative to the normal to said plane of the substrate, said optical main axis extending in a plane of polarization of the second polarizer, and said planes of polarization crossing each other substantially at right angles.

By virtue of the fact that the optical main axis of the first retardation foil extends parallel to the direction of polarization of the first polarizer, said foil only passes light which oscillates in the plane of polarization, i.e. along the optical main axis of the retardation foil, so that birefringence does not occur and hence the development of stray

components is substantially absent. Upon passing through the second retardation foil, the polarized light passed is not subject to birefringence either because, at the location of said second retardation foil, it oscillates in a direction at right angles to the optical main axis of the second retardation foil. In the case of polarizers crossing each other at right angles complete extinction then occurs. Advantageously, both retardation foils are provided on the same side of the liquid-crystal layer.

For the retardation foils use can be made of either inorganic or organic material.

To minimize the remaining stray components, if any, in the light passed (brought about by the type of material used for the retardation foil), a preferred embodiment of a display device in accordance with the invention is characterized in that the retardation foils predominantly comprise polymerized or vitrified nematic liquid-crystalline material, with the liquid-crystal molecules in the polymerized, nematic liquid-crystalline material extending in a plane of polarization and exhibiting a tilt angle relative to the plane of the substrate.

By virtue thereof, the directions of orientation of the liquid-crystal molecules in the polymerized, nematic liquid-crystalline material in the retardation foils are substantially constant.

The direction of orientation of a liquid-crystal molecule is to be understood to mean in this context the perpendicular projection of the director of the liquid-crystal molecule on a substrate.

The direction of orientation remains constant if there is a spread between the (average) tilt angles in the various retardation foils as a result of fabrication spread. Thus, an optical component provided with one or more such retardation foils can be manufactured in a simple manner without a spread in optical properties.

The liquid-crystalline material may be partly polymerized, but, preferably, it is polymerized substantially completely.

Dependent upon the method of manufacture, the liquid-crystal molecules in the polymerized or vitrified nematic, liquid-crystalline material have a tilt angle relative to the substrates, which varies (for example by using surface-active substances) or which is substantially constant. This can be determined by means of conoscopy or microscopy using polarized light (polarizing microscopy).

During the manufacture of a retardation foil, the tilt angle of the liquid-crystal molecules (director profile) can be obtained by using a polymeric material which is

formed from a liquid-crystal monomer.

In principle, all liquid-crystalline polymeric materials can be used as the material for the retardation foils. However, use is preferably made of liquid-crystalline polymeric materials which are the reaction product of monomers or of a mixture of monomers comprising a reactive group. Such polymeric materials have the advantage that the liquid-crystalline monomers can be oriented prior to polymerization. Polymerization causes such an orientation to be fixed as it were. It is noted that such a mixture may additionally comprise non-reactive (liquid-crystalline) materials and/or non-liquid-crystalline monomers without losing its liquid-crystalline character. The reactive monomers preferably comprise a liquid-crystalline group.

For the reactive group use can be made of vinyl ethers, thiolene systems or epoxy groups. However, use is preferably made of reactive groups in the form of (meth)acrylate groups. Monomers comprising a(n) (meth)acrylate group proved to be excellently processable. In principle, the monomers can be thermally polymerized. In practice, radical-polymerization under the influence of actinic radiation, in particular UV light, is the simplest way of polymerizing the monomers. This has the advantage that persons skilled in the art can choose the temperature at which the mixture should be polymerized themselves. The choice of the temperature often is very important as the liquid-crystalline properties of the mixture to be polymerized are governed to a substantial degree by the temperature.

Preferably, the mixture to be polymerized also comprises monomers having two or more reactive groups of the above-mentioned type. During polymerization, the presence of such monomers leads to the formation of a three-dimensional network. This causes the optical properties of the inventive retardation foil to become less sensitive to variations in temperature. In particular for foils which are employed at different temperatures, such a small temperature-dependence of the optical properties is very favorable.

Liquid-crystalline molecules which can be used within the scope of the invention correspond to the general formula

$$A\text{-}B\text{-}M\text{-}(B)\text{-}(A)$$

In this formula, M represents a group whose chemical structure and rigid conformation cause the molecule to become highly anisotropic. Suitable M groups are disclosed, inter alia, in USP 4,398,803 and WO 95/24454. B represents a so-called spacer group. Dependent upon the desired properties, the monomers used comprise one or two spacer groups. Spacer groups

are also known from the above-mentioned Patent publications. A represents a reactive group of the above-mentioned type. The liquid-crystalline molecules may comprise one or two reactive groups. As stated above, a part of the liquid-crystalline molecules in the mixture may be non-reactive. In that case, these molecules do not comprise A-type groups.

A preferred embodiment of the display device is characterized in that the polymerized material comprises liquid-crystalline molecules which are provided, at one end, with a non-polar group and, at the other end, with a polar group. The presence of this type of liquid-crystal molecules causes the liquid-crystalline material of the mixture to be polymerized to assume the homeotropic phase at a short distance from the substrate. As a result, the desired ordering of the tilt in the liquid-crystalline material of the retardation foil takes place almost spontaneously. Consequently, in this case treatments with electric fields to induce said tilt are redundant. This simplifies the manufacture of such foils.

Liquid-crystalline molecules having a polar end and a non-polar end correspond to the general formula

$$R\text{-}B\text{-}M\text{-}Z$$

where B and M have the above-mentioned meaning. In this case, the spacer group B serves as the non-polar group of the molecule and Z represents a polar group, such as -CN, -OH, $-NO_2$, -COOH or $-C(O)O-CH_3$, but also phosphates, phosphonates and sulphonates are possible. R represents a further substituent.

A further preferred embodiment of the display device is characterized in that at the end provided with the non-polar group, the liquid-crystal molecules are covalently bonded to the polymerized material. This is achieved if for R use is made of a reactive group of the above-mentioned type. By virtue of this measure, the optical properties of the inventive retardation foil become less sensitive to variations in temperature. In particular for foils which are employed at different temperatures, such a small temperature-dependence of the optical properties is very favorable. By virtue of said measure, the foils can also incidentally withstand (for example during storage or transport, or in automotive applications) very high temperatures without the molecular order being lost.

The tilt may be substantially uniform. Alternatively, during the manufacture of the display device, a pretilt can be induced in one or both boundary surfaces, for example by means of the method described in USP 5,155,610. Dependent upon this pretilt, the optically anisotropic layer obtains, for example, a combined "splay and bend" deformation. During the manufacture, it is also possible to influence the eventual director profile by means of electric and/or magnetic fields. This may result, for example, in a

preferred direction for the directors. Such a preferred direction can alternatively be attained during polymerization in the smectic C-phase of liquid-crystalline materials.

A further preferred embodiment of a liquid-crystalline display device is characterized in that a birefringent layer is situated between the display cell and each of the retardation foils, said birefringent layer having an optical main axis extending in a plane parallel to the substrates. It has been found that, in this manner, a further reduction of the so-called grey-scale inversion is achieved, in particular, if the optical axes of the birefringent layers and the retardation foils cross each other, substantially at right angles, on the same side of the display cell. For the manufacture of the birefringent layers, use can advantageously be made of liquid-crystalline materials which are polymerized.

In terms of the manufacture, it is advantageous to provide both retardation foils on either side of a transparent (synthetic resin) support. A display device comprising such a construction is characterized in that the tilt angle(s) in the retardation foils are of opposite sign, viewed from the common support.

Preferably, the assembly of a polarizer and the retardation foils is manufactured in one piece and subsequently combined with the display device. Consequently, an optical component provided with a polarizer in accordance with the invention is characterized in that said component comprises a retardation foil having an optical main axis which is tilted relative to the normal to one of the surfaces of the polarizer, and said optical main axis extends in a plane of polarization of the polarizer.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

In the drawings:

Fig. 1 is a schematic, cross-sectional view of a part of a liquid-crystal display device in accordance with the invention,

Fig. 2 shows a part of the device shown in fig. 1,

Fig. 3 schematically explains the optical behavior of a known device, which is similar to the one shown in Fig. 2, by means of so-called indicatrices,

Fig. 4 schematically shows the differences between the display device in accordance with the invention and the display device in accordance with Fig. 3,

Figs. 5 to 10 show variants of a retardation foil to be used,

Fig. 11 shows a variant of a display device in accordance with the

invention,

Fig. 12 shows transmission/voltage curves of a customary display device and of display devices shown in Figs. 1 and 11,

Fig. 13 shows the structural formulas of a number of materials used, and

Fig. 14 shows yet another retardation foil.

Fig. 1 is a schematic, cross-sectional view of a part of a liquid-crystal display device comprising a liquid-crystal cell 1 with a twisted nematic, liquid-crystalline material 2 sandwiched between two substrates 3, 4, for example, of glass, which are provided with electrodes 5, 6. The device further comprises two polarizers 7, 8 whose directions of polarization cross each other at right angles. The cell further includes orientation layers (not shown), which orient the liquid-crystalline material on the inner surfaces of the substrates, in this example, in the direction of the polarization axes of the polarizers, so that the cell has a twist angle of 90 degrees. In this case, the liquid-crystalline material has a positive optical anisotropy and a positive dielectric anisotropy. Thus, if a voltage is applied to the electrodes 5, 6, the molecules and hence the directors are oriented in accordance with the field. Therefore, in an ideal case, all molecules extend substantially perpendicularly to both substrates (situation 11 in Fig. 2). In practice, however, this situation requires too high a voltage; at customary voltages, the molecules make a small angle with the normal to the substrates 3, 4, which corresponds to situation 12 in Fig. 2. Consequently, when the cell is viewed from direction 13, the viewer looks much more in the direction of the molecules, so that light which is still passed at this voltage is subject to a substantial and, in addition, asymmetric angle-dependence. This angle-dependence can be explained by means of the so-called "optical indicatrix", i.e. a three-dimensional geometric display of the refractive index for each direction in which the vector of the electric-field component of the light can oscillate. In the case of an optically isotropic material, this optical indicatrix is spherical, in the case of a biaxial material it is an ellipsoid, and in the case of a uniaxial material it is an ellopsoid with an axial axis of symmetry. As, in an ideal case, the liquid-crystalline layer in the driven state is uniaxial across almost its entire thickness (in almost all molecular layers, except for the molecular layers near the substrates, the molecules extend at right angles to the substrates), situation 11 shown in Fig. 2 can be represented by indicatrix 14 in Fig. 3, which is an ellipsoid whose main axis extends transversely to the liquid-crystal layer, with the refractive index n_z at right angles to the substrates being larger than the

refractive index in the planes extending parallel to the substrates ($n_x = n_y$).

As the liquid is not isotropic, birefringence occurs. It can be demonstrated that this birefringence can be compensated for by an indicatrix 15 in fig. 3, which is an ellipsoid whose axis extends transversely to the liquid-crystal layer, with the refractive index n_z at right angles to the substrates being smaller than the refractive index in the directions parallel to the substrates ($n_x = n_y$).

In practice, however, this situation requires too high a voltage; at the customary voltages, the molecules make a small angle with the normal to the substrates 3, 4, which corresponds to situation 12 in Fig. 2. As a result, when the cell is viewed from direction 13, a viewer looks much more in the direction of the molecules. In this more practical situation, the indicatrix 14' has a main axis which makes a small angle with the axis transverse to the liquid-crystal layer; indicatrix 14 is slightly tilted, as it were, relative to this axis. In this case, a good compensation is attained by a compensator layer 9 having an indicatrix 15', which is obtained by tilting indicatrix 15 in the same manner, as it were, relative to this axis.

Fig. 4 shows, on the left-hand side, the same situation, i.e. the liquid 2 with the associated indicatrix 14', and the compensator layer 9 with the associated indicatrix 15', in this case, the liquid and the compensator layer are sandwiched between crossed polarizers 7, 8. As shown on the right-hand side of Fig. 4, the display device in accordance with the invention comprises, in this example, two retardation foils 9 which, in this example, predominantly contain polymerized, nematic liquid-crystalline material having a tilt angle of the liquid-crystal molecules in the polymerized, nematic liquid-crystalline material with respect to the substrates and average directions of orientation of the liquid-crystal molecules in the polymerized, nematic liquid-crystalline material, which make an angle of 90 degrees with each other, viewed at right angles to the substrates. In this example, the polymerized liquid-crystal molecules (indicated by means of directors 23) of the retardation foil 9^a extend parallel to the direction of polarization of polarizer 8 and exhibit an average tilt angle α of 30 degrees. In this example, the polymerized liquid-crystal molecules of retardation foil 9^b extend parallel to the direction of polarization of polarizer 7 and also exhibit an average tilt angle of 30 degrees. To explain the operating principle, the liquid layer 2 is divided into three parts which each have their own indicatrix 16, 17 and 18. Indicatrix 21 of retardation foil 9^a now compensates, as it were, indicatrix 18 and a part of indicatrix 17, while indicatrix 22 of retardation foil 9^b now compensates, as it were, indicatrix 16 and the other part of indicatrix 17. It has been found that the use of separate retardation foils 9^a, 9^b leads

to a better result regarding the grey-scale inversion and angle-dependence than the use of a single foil, which is represented by indicatrix 15'.

An incident light beam 25 is linearly polarized by the polarizer 7 in a direction at right angles to the plane of the drawing. As the optical main axis of the retardation foil 9^b in accordance with the invention extends in a plane of polarization of polarizer 7, this retardation foil does not exert a birefringent influence on the light, which oscillates in the plane of polarization, and oscillations at right angles to the plane of polarization do not take place. The more the molecules in the retardation foil extend in one plane at right angles to the direction of propagation of the polarized light, the better oscillations at right angles to the plane of polarization (and hence elliptically polarized light) can be precluded, as in the case of light oscillating in a direction at right angles or parallel to the optical main axis no birefringent effect occurs. This is achieved, in particular, by polymerized, nematic liquid-crystalline material having no twist or a negligible twist, but it can also be achieved with retardation foils of an inorganic material. Viewed along the directors, the liquid 2 exhibits almost isotropic behavior (in the driven state) so that the polarized light reaches the retardation foil 9^a, while it oscillates in a plane at right angles to the optical main axis of the retardation foil 9^a. This means that birefringence again does not occur and that the beam is completely extinguished.

The average tilt angle in the retardation foils 9^a, 9^b may be different, for example 30 and 20 degrees. However, as long as the molecules in the retardation foil extend in one plane at right angles or parallel to the direction of polarization of the polarized light (and hence light oscillating in a direction at right angles to or parallel to the optical main axis is not subject to birefringence) a variation in the tilt angle does not affect the operation and a spread in the size of this angle during the manufacture hardly, if at all, leads to a spread in the optical properties of the final product.

On the one hand, the average tilt angle in the retardation foils 9^a, 9^b is preferably larger than 5 degrees because smaller angles hardly lead to an improvement of the angle-dependence or grey-scale inversion; on the other hand, this tilt angle should preferably not exceed 70 degrees because, otherwise, the retardation foils acquire too much axial symmetry as a function of the viewing angle. The best results are achieved at values ranging between 10 degrees and 40 degrees.

The retardation foils can be manufactured, for example, by providing a supporting plate or substrate with orienting layers, for example rubbed polyimide or polyvinyl alcohol, so that a high tilt is attained. Instead of rubbed polyimide, use can

alternatively be made of a linearly polarized photo-sensitive material (for example a photopolymer such as poly(vinyl 4-ethoxy-cinnamate) for orienting the liquid-crystal molecules. It is alternatively possible to use a rubbed substrate.

The liquid-crystalline material provided on the substrate prepared as described hereinabove comprises liquid-crystalline molecules which not only adopt the orienting effect of the substrate (achieved by rubbing or by means of an orientation layer) but also show a tendency, at a free surface, to orient themselves at right angles to said surface (homeotropic alignment). As a result, the orientation of the molecules at the substrate will be substantially planar or exhibit a small tilt angle (indicated in Fig. 4 by directors 23 in retardation foil 9^a). At a slightly greater distance from the surface, the orienting influence of the orientation layer will be slightly smaller, so that, in this layer, the molecules will exhibit a more homeotropic alignment and the directors 23' on average will have a slightly larger tilt angle. At the surface, the alignment of the molecules is almost exclusively homeotropic (directors 23"). This is also dependent on the thickness of the layer. Also in retardation foil 9^b, the average tilt angle through the foil increases from practically zero degrees at the plane of orientation to approximately 90 degrees at the free surface.

A suitable mixture for the liquid-crystalline material of the retardation foils comprises 40 wt.% of a reaction LC material (a mixture of 25 wt.% 296 (see c, Fig. 13) and 75 wt.% 716 (see d, Fig. 13)) and 60% of a non-reactive cyanobiphenyl mixture. This mixture was provided by immersing the entire substrate or by spinning the mixture onto the rubbed surfaces, whereafter it was polymerized by means of UV-radiation in a nitrogen atmosphere or vitrified. As, on the one hand, the molecules are oriented with a small tilt angle at the supporting surface, and, on the other hand, are aligned substantially homeotropically at the surface, an average tilt angle α is obtained (Fig. 4). A similar structure is attained with molecules which assume a homeotropic alignment at the substrate and a planar alignment at the surface. This can alternatively be achieved by means of other methods (provision by means of a doctor blade) and substrates (directly onto glass). Another mixture, which did not comprise non-reactive liquid-crystalline material, so that the strength of the layer was increased, was composed of 25 wt.% 296 (see c, Fig. 13) and 75 wt.% 76 (see e, Fig. 13).

The retardation foils 9^a, 9^b are provided, on the adjacent polarizer, preferably on one side of the liquid 2. Such a combination, in which both retardation foils are situated on one side of a support 10, is shown in Fig. 5. As the molecules 23" of retardation foil 9^a are homeotropically aligned at the interface between the retardation foils 9^a

and 9^b, the homeotropic alignment can be induced in a simple manner in the retardation foil 9^b which is situated above the retardation foil 9^a. If the number of molecules in the mixture which exhibit a planar orientation is sufficient, then the tilt angle decreases, so that an average angle of approximately 25 degrees is formed. The preferred direction in the retardation foil 9^b is introduced, for example, by mechanical shearing or by covering the entire compensator layer, during the polymerization operation, with a thin layer (film) provided with an orienting layer.

In the retardation foil shown in Fig. 6, the tilt angle in foil 9^b at the interface between the retardation foils 9^a and 9^b is made substantially parallel to the interface by means of a rubbing treatment. A thin, transparent, optically isotropic protective layer 29 is provided in order not to disturb the underlying perpendicular alignment.

The directions of orientation, as shown in Fig. 4 for the layers 9^a, 9^b (combined splay and bend configuration), in which the tilt angle at the free surface may also be smaller than 90 degrees can also be obtained by using a liquid-crystalline starting material which spontaneously adopts such a configuration because the ratio K_{11}/W between the elastic constant K_{11} and the (polar) anchoring energy coefficient W is chosen to be smaller than 300 nm. After a substrate has been oriented, it is coated, in the manner described hereinabove, with the liquid-crystalline material, whereafter a polymerization step is carried out.

Fig. 7 schematically shows a variant of the retardation foil 9^a of Fig. 4, said retardation foil 9^a comprising sub-layers 19, 19', 19" and 19'". In this case, the tilt angles in each one of said sub-layers 19 are, for example, constant. The directions of orientation of the associated molecules (indicated by means of the directors 23, 23', 23" and 23"') and hence the optical main axis extend, in this example, in the plane of the drawing of retardation foil 9^a. The optical main axis of the retardation foil 9^a may alternatively extend in another suitable plane, which differs from the plane of the drawing.

In the retardation foil shown in Fig. 8, the directions of orientation of the associated molecules (indicated by means of the directors 23, 23', 23" and 23'") in successive sub-layers 19, 19', 19", 19'" of the retardation foil 9^a, make a small angle with each other, viewed at right angles to the retardation foil. As a result, the optical main axis of the retardation foil 9^a extends in a plane which makes an angle with the plane of the drawing. In a finished device, the optical main axis of the retardation foil 9^a extends again in a plane of polarization of the associated polarizer 8.

In the retardation foil shown in Fig. 8, the directions of orientation of the molecules in successive sub-layers 19 are different at the boundary between two sub-layers,

whereas they are substantially equal in the retardation foil of Fig. 9. Nevertheless, the direction of orientation of director 23' in sub-layer 19' differs from that of director 23 due to the fact that a small quantity of a chiral component is added to the mixture of liquid-crystalline materials to be polymerized or vitrified. The polymerized (vitrified) sub-layer 19 serves as the orientation layer for the sub-layer 19' in a subsequent process step. If necessary, the material of the sub-layer 19' may again contain a small quantity of a chiral component. The relevant chiral component may have the same chirality, so that the angle which the optical main axis of the complete retardation foil makes with the plane of the drawing is increased with respect to the angle which the optical main axis of the sublayer 19 makes with the plane of the drawing. In the case of an opposite chirality, the angle which the optical main axis of the retardation foil makes with to the plane of the drawing is reduced; dependent upon the quantity of the chiral component and the thickness of the sub-layer 19', the optical main axis of the complete retardation foil may again extend in the plane of the drawing. Of course, many intermediate forms are also possible.

Fig. 10 shows an optical component comprising a polarizer 8 with a retardation foil 9^a whose optical main axis makes an angle (for example α) with the surface of the polarizer. The retardation foil 9^a can be obtained by obliquely vapor-depositing a suitable material, such as tantalum oxide or tungsten oxide. In this case, the direction of the optical main axis is determined only by the vapor-deposition process. Other possible materials are silicon oxide or titanium oxide. It is alternatively possible to provide said materials on a saw-tooth structure.

Fig. 11 schematically shows the structure of a further liquid-crystalline display device in accordance with the invention. In comparison with the device shown in Fig. 4, this device additionally comprises two birefringent layers 24^a, 24^b whose optical main axis 26^a, 26^b, respectively (which, in this example, are not tilted relative to the normal to the surface) cross the optical main axes of the nearby retardation foils (determined by the direction of the directors 23) at right angles; these birefringent layers thus do not influence perpendicularly incident light, however, it has been found that the introduction of these layers reduces the angle-dependence and grey-scale inversion. Reference numerals 27^a, 27^b indicate the directions of orientation of the liquid-crystal molecules in the liquid 2 on the substrates. Supports may be sandwiched between the foils and the birefringent layers, however, this is not necessary. It is alternatively possible that a support is situated between a polarizer and an assembly of supports.

Figs. 12a, 12b and 12c show the transmission as a function of the voltage,

viewed at right angles to the device (solid line) and at a specific angle (broken line). A noticeable feature is that in Fig. 12^a (retardation foil and birefringent layer both absent), as the voltage increases, the transmission, viewed at an angle, decreases from a maximum to zero, whereafter it increases again (grey-scale inversion). In a display device in accordance with Figs. 1 and 11, the transmission remains very small (Fig. 2^b) or practically zero (Fig. 12c) even at relatively high voltages.

The optical axes 26^a, 26^b of the birefringent layers 24^a, 24^b do not necessarily have to cross each other at right angles. They may also intersect the optical axes of the nearby retardation foils at an angle other than 90 degrees. It is even possible to allow the number of stray components to increase, if the number of grey levels to be represented in a grey scale is small. In this case, the optical axes of the retardation foils do not necessarily have to extend in a plane of polarization. The angle which these optical axes make with each other may then be chosen to range between 60 and 120 degrees.

The retardation foils can also be manufactured, for example, by providing two glass plates (whether or not covered with ITO) with orienting layers, for example polyimide rubbed in anti-parallel directions, so that a high tilt is attained, which glass plates are held at a distance from each other by means of spacers. Between the glass plates there is provided a suitable mixture of LC monomers, for example a mixture of 25 wt.% C6M (see a, Fig. 13) and 74 wt.% 495 (see b, Fig. 13) and a suitable initiator, whereafter this mixture is polymerized by UV radiation at 100 °C under the influence of a weak electric field.

A compensator layer is formed by joining two such retardation foils having different tilt angles, the directions of orientation of the molecules being rotated through approximately 90 degrees with respect to each other.

In the case of retardation foils having a substantially constant tilt angle, also reactive liquid-crystal molecules can be used as the starting material, which molecules are brought to the smectic C-phase between surfaces which bring about a homeotropic alignment, whereafter the molecules are polymerized by means of UV radiation. In this manner, large tilt angles (in the range between 40 and 89 degrees) can be achieved. As the eventual setting is temperature-dependent, the eventual angle can be influenced via the temperature setting. By way of example, use is made of a mixture comprising 54.5 wt.% C6H (No. 23) (see f, Fig. 13) and 44.5 wt.% No. 79 (see g, Fig. 13) and a suitable initiator. The mixture was sandwiched between two glass plates which were provided with a layer of a homeotropically aligning material, for example a polyimide such as SE 7511L which can be obtained from Nissan Chemical. The mixture was subsequently cooled from

155 °C (isotropic state) to 82 °C (smectic state). To attain a uniform alignment, a minor shift of the smectic layers may be advantageous. Subsequently, the reactive molecules were polymerized by means of UV radiation. Fig. 14 shows how two such retardation foils 9^a, 9^b having a constant tilt angle β are combined into a compensator layer 9.

The retardation foils may be provided on the outside or the inside of the cell. In one example, they are be provided directly onto the substrates, in another example such a foil is provided on an other layer present in the cell, for example a protective layer or top coating. If the hardness of the retardation foil is sufficient, its small thickness (up to approximately 600 nm) renders it very suitable for use as a top coating.

In another embodiment, viz. a colour liquid crystal display device, having a colour filter, the retardation foil has a patterned structure, of different retardation values (e.q. by varying its thickness), in registration with elements of the colour filter. For each separate colour the retardation of the associated part of the foil is optimized for a wavelength associated with said colour.

Instead of driving by means of electrodes on both supporting plates, as described hereinabove, use is alternatively made of thermal addressing or addressing via plasma (plasma-addressed LCD).

In summary, the invention relates to a liquid-crystal display device, in which one or both polarizers in the display cell are provided with retardation foils, which each have an optical axis extending in one of the planes of polarization and being tilted relative to the associated plane of the substrate. By virtue thereof, a substantially complete extinction between polarizers crossing each other at right angles is achieved, while, in addition, a reduction of the angle-dependence and an improved grey-scale inversion are achieved.

CLAIMS:

1. A liquid-crystal display device having a display cell which comprises a layer of a nematic, liquid-crystalline material between two substantially parallel substrates, and a first and a second polarizer, which display cell is provided with a retardation foil an optical main axis of which is tilted relative to the normal to a plane of one of the substrates, characterized in that the optical main axis extends in a plane of polarization of the first polarizer, and the display cell is provided with a second retardation foil with an optical main axis which is tilted relative to the normal to said plane of the substrate, said optical main axis extending in a plane of polarization of the second polarizer, and said planes of polarization crossing each other substantially at right angles.

2. A liquid-crystal display device as claimed in Claim 1, characterized in that at least one of the retardation foils comprises predominantly polymerized or vitrified, nematic liquid-crystalline material, the liquid-crystal molecules in the polymerized or vitrified nematic, liquid-crystalline material extending in a direction of orientation parallel to a plane of polarization and exhibiting, in said direction of orientation, a tilt angle relative to the plane of the substrate.

3. A liquid-crystal display device as claimed in Claim 1, characterized in that the retardation foil predominantly comprises polymerized or vitrified nematic, liquid-crystalline material, the liquid-crystal molecules in the polymerized or vitrified nematic, liquid-crystalline material exhibiting a tilt angle, in the direction of orientation, relative to the plane of the substrate, and, on average over the thickness of the layer of polymerized liquid-crystalline material, extending in a direction of orientation parallel to a plane of polarization.

4. A liquid-crystal display device as claimed in Claim 1, characterized in that the retardation foil comprises a material of the group formed by tantalum oxide, tungsten oxide, silicon oxide and titanium oxide.

5. A liquid-crystal display device as claimed in Claim 2, 3 or 4, characterized in that the retardation foils are provided on either side of a transparent support, and the tilt angles in the retardation foils, viewed from the common support, increase from the surfaces of the support.

6. A liquid-crystal display device as claimed in Claim 2, 3 or 5,

characterized in that the tilt angle of the liquid-crystal molecules in the polymerized or vitrified nematic, liquid-crystalline material in at least one of the retardation foils increases or decreases, viewed in a direction at right angles to the retardation foil.

7. A liquid-crystal display device as claimed in Claim 2, 3 or 5, characterized in that the tilt angle of the liquid-crystal molecules in the polymerized or vitrified, nematic liquid-crystalline material in at least one of the retardation foils is substantially constant, viewed in a direction at right angles to the retardation foil.

8. A liquid-crystal display device as claimed in any one of the preceding Claims, characterized in that a birefringent layer of which an optical main axis extends in a plane parallel to the substrates is situated between the display cell and each one of the retardation foils.

9. A liquid-crystal display device as claimed in any one of the preceding Claims, characterized in that the polymerized or vitrified material comprises liquid-crystal molecules which, at one end, are provided with a non-polar group and, at the other end, with a polar group.

10. An optical component comprising a polarizer, characterized in that said component is provided with a retardation foil an optical main axis of which is tilted relative to the normal to one of the surfaces of the polarizer, and the optical main axis of the retardation foil extends in a plane of polarization of the polarizer.

11. An optical component as claimed in Claim 10, characterized in that this component comprises at least a second retardation foil an optical main axis of which is tilted relative to the normal to said surface, which optical main axis extends in a plane which crosses the plane of polarization substantially perpendicularly.

12. An optical component as claimed in Claim 11, characterized in that the retardation foils are situated on both sides of a transparent support, and the tilt angles in the retardation foils, viewed from the common support, increase from the surfaces of the support.

13. An optical component as claimed in Claim 10 or 11, characterized in that the retardation foil predominantly comprises polymerized or vitrified nematic, liquid-crystalline material, the liquid-crystal molecules in the polymerized or vitrified nematic, liquid-crystalline material extending in a direction of orientation parallel to a plane of polarization, and exhibiting, in the direction of orientation, a tilt angle relative to the surface.

14. An optical component as claimed in Claim 10 or 11, characterized in that the retardation foil predominantly comprises polymerized or vitrified nematic, liquid-

crystalline material, with the liquid-crystal molecules in the polymerized or vitrified nematic, liquid-crystalline material exhibiting, in the direction of orientation, a tilt angle relative to the plane of the substrate, and, on average over the thickness of the layer of polymerized liquid-crystalline material, extending in a direction of orientation parallel to a plane of polarization.

15. An optical component as claimed in Claim 10 or 11, characterized in that the tilt angle of the liquid-crystal molecules in the polymerized or vitrified nematic, liquid-crystalline material in a retardation foil increases or decreases, viewed in a direction at right angles to the foil.

16. An optical component as claimed in Claim 10 or 11, characterized in that the tilt angle of the liquid-crystal molecules in the polymerized or vitrified nematic, liquid-crystalline material in a retardation foil is substantially constant, viewed in a direction at right angles to the foil.

17. An optical component as claimed in any one of Claims 11 to 16, characterized in that the optical component also comprises a birefringent layer an optical main axis of which extends in a plane parallel to the surface of the polarizer.

18. An optical component as claimed in Claim 17, characterized in that the optical main axes of the retardation foil and the birefringent layer cross each other substantially at right angles.

19. An optical component as claimed in any one of Claims 13 to 18, characterized in that the polymerized or vitrified material comprises liquid-crystal molecules which are provided, at one end, with a non-polar group and, at the other end, with a polar group.

20. An optical component as claimed in Claim 19, characterized in that, at the end provided with the non-polar group, the liquid-crystal molecules are covalently bonded to the polymerized or vitrified material.

21. An optical component comprising a polarizer as claimed in Claim 19 or 20, characterized in that the polar group comprises -CN, -OH, $-NO_2$, -COOH , -C(O)O-CH_3, a phosphate, a phosphonate or a sulphonate.

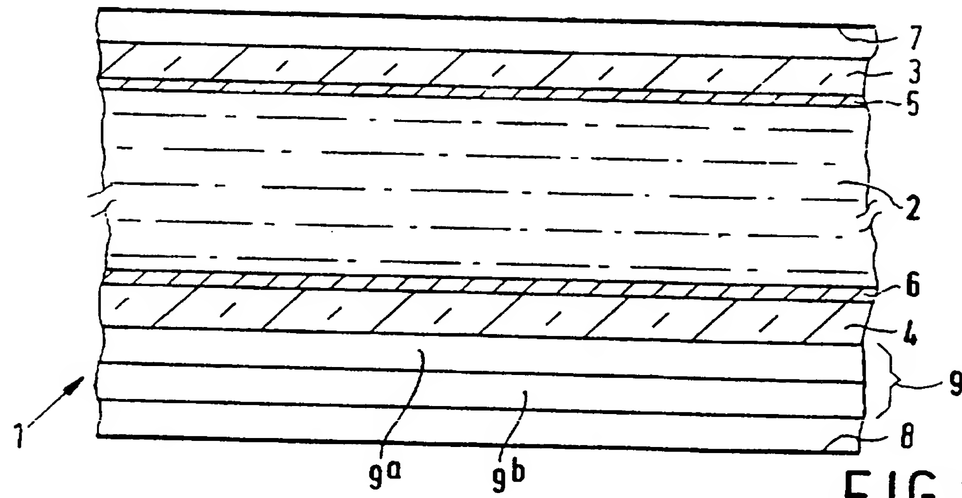


FIG.1

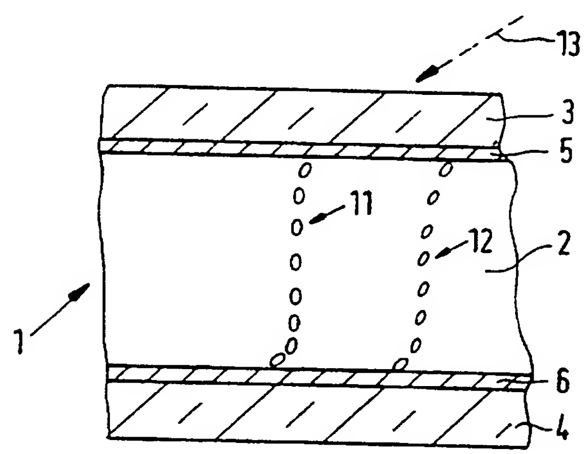


FIG.2

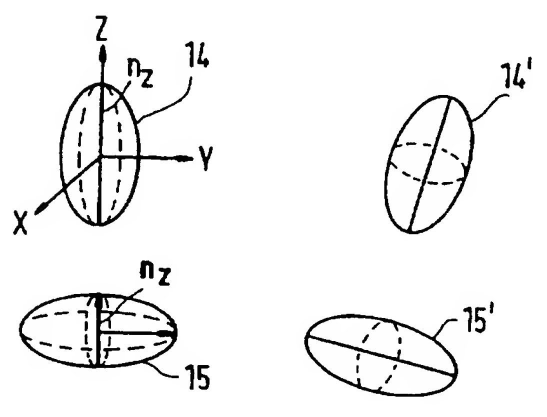


FIG.3

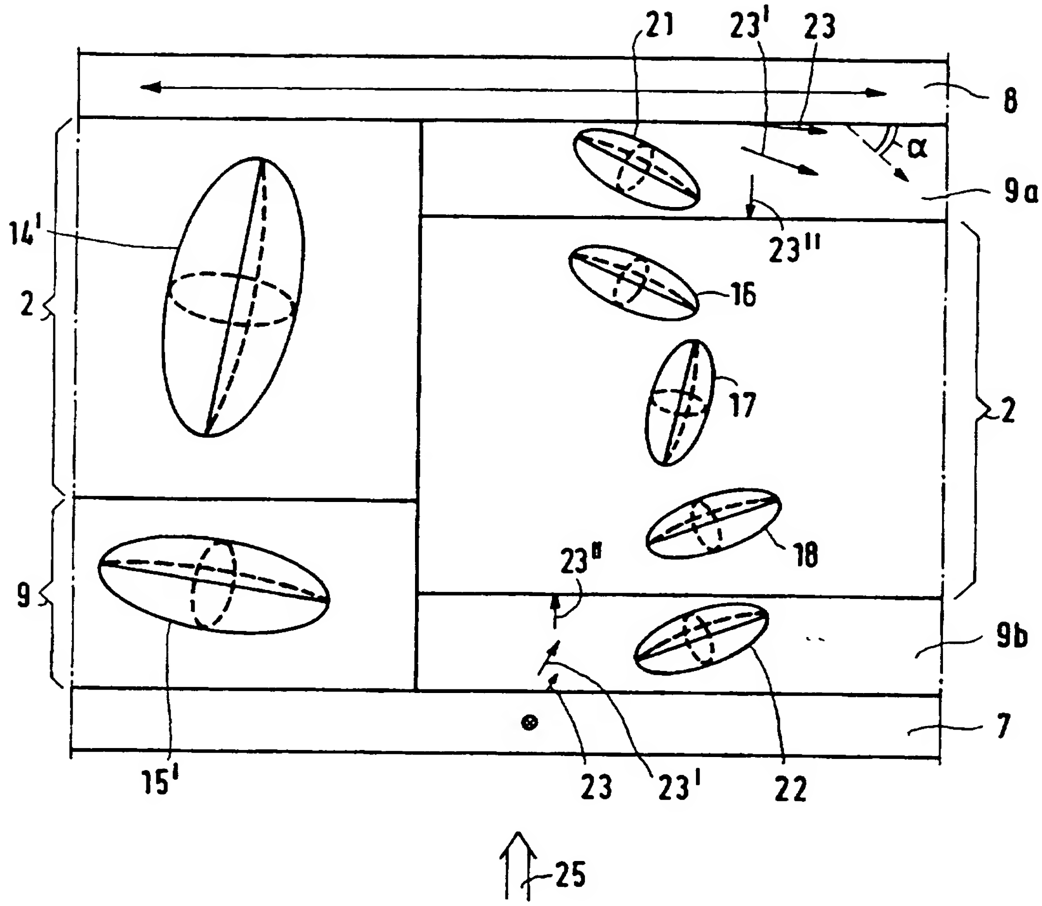


FIG. 4

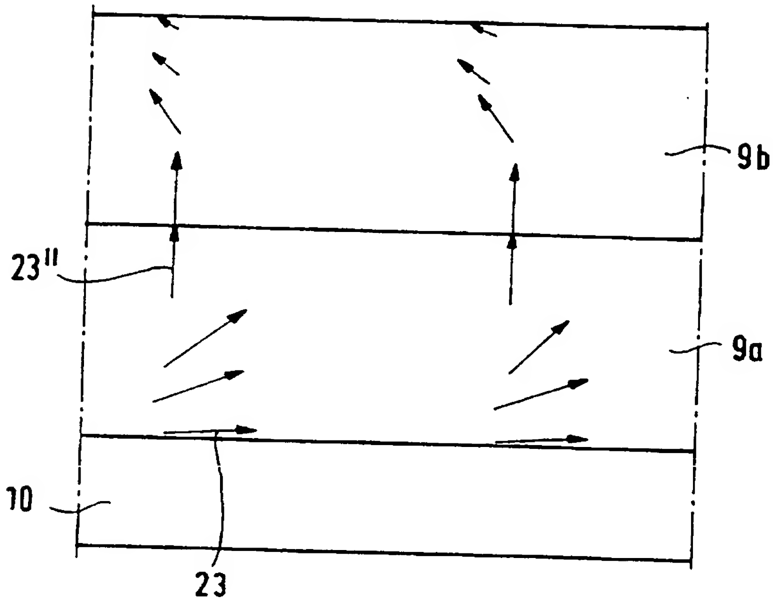


FIG.5

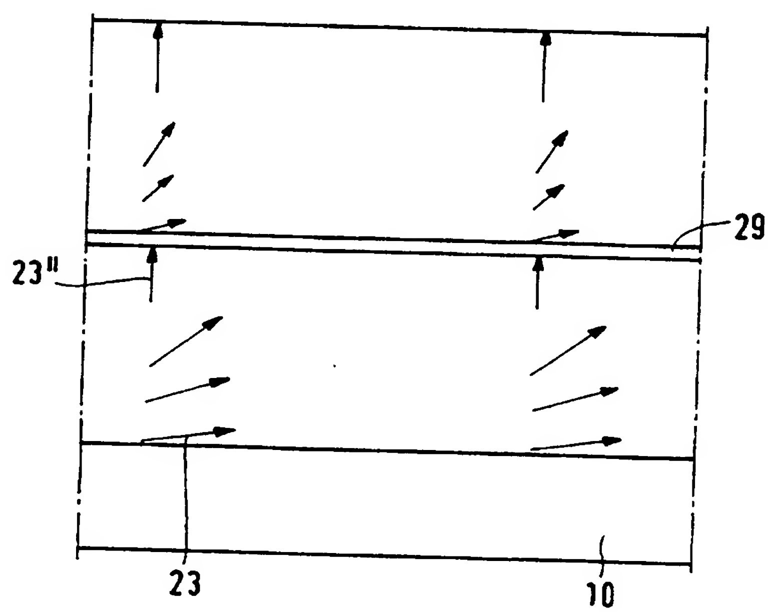


FIG.6

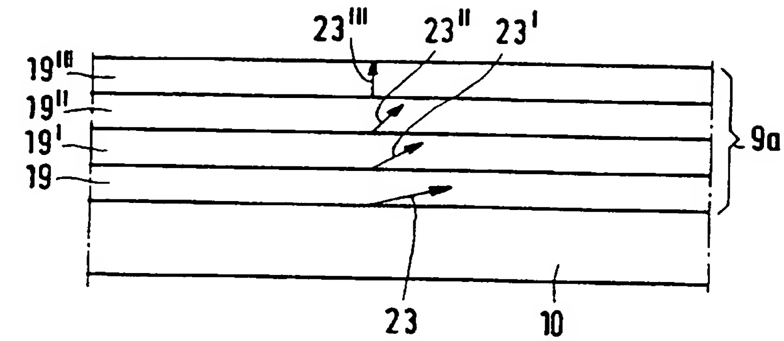


FIG.7

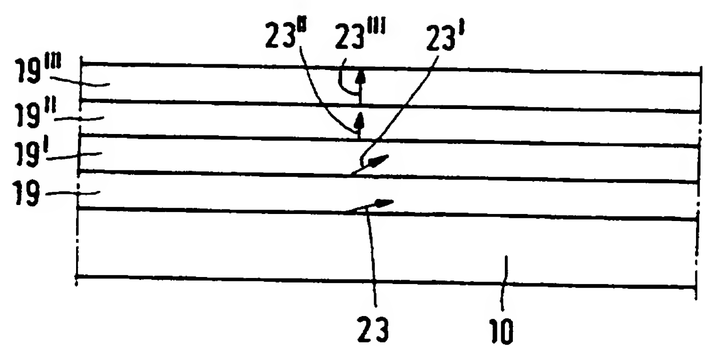


FIG.8

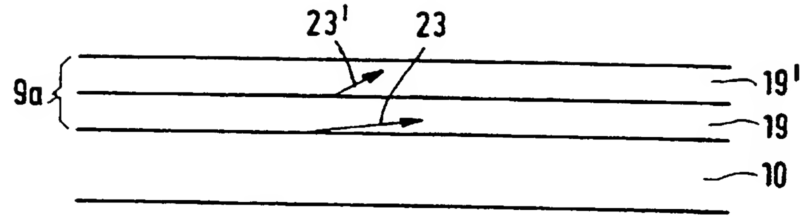


FIG.9

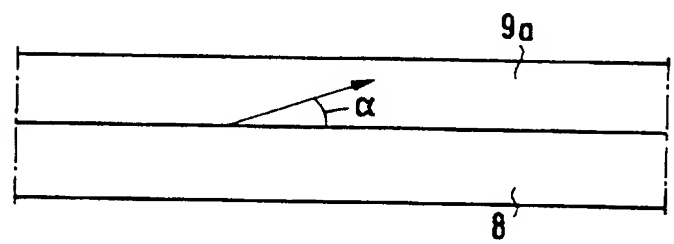


FIG.10

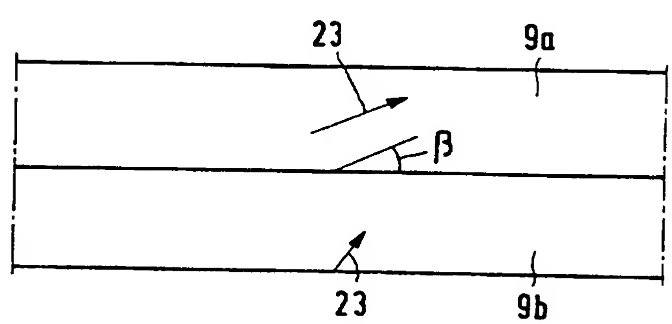


FIG.14

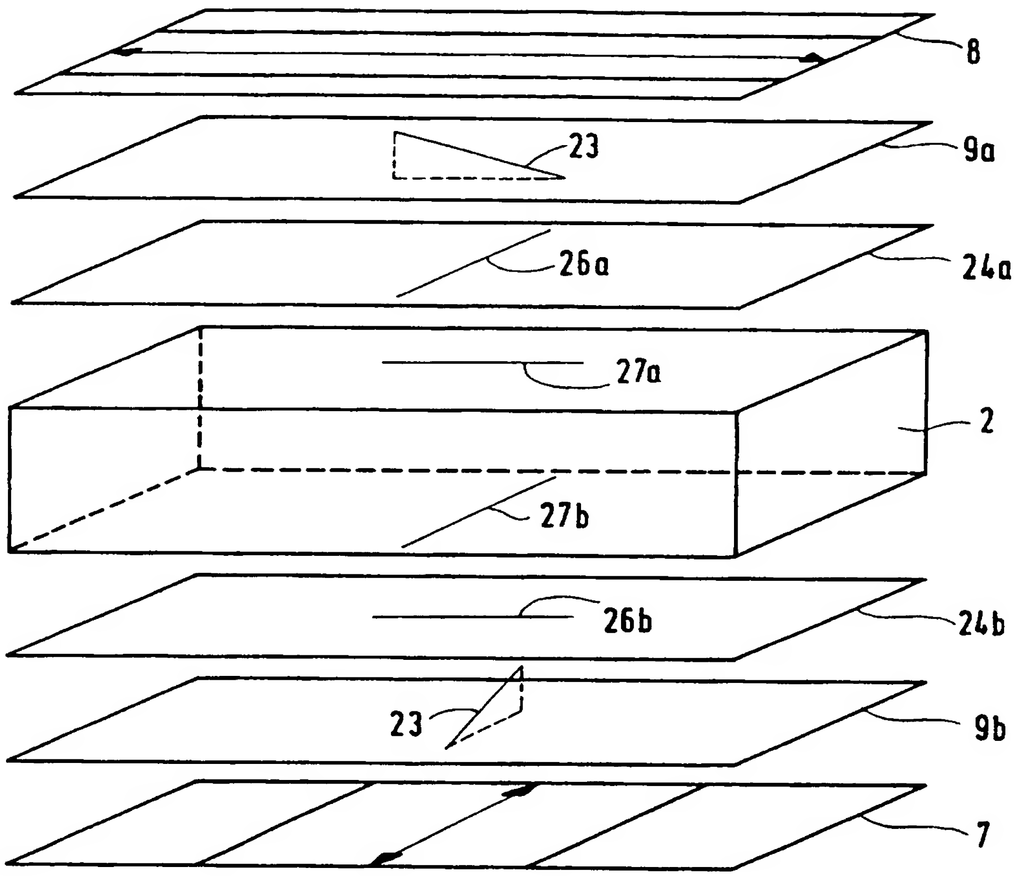


FIG. 11

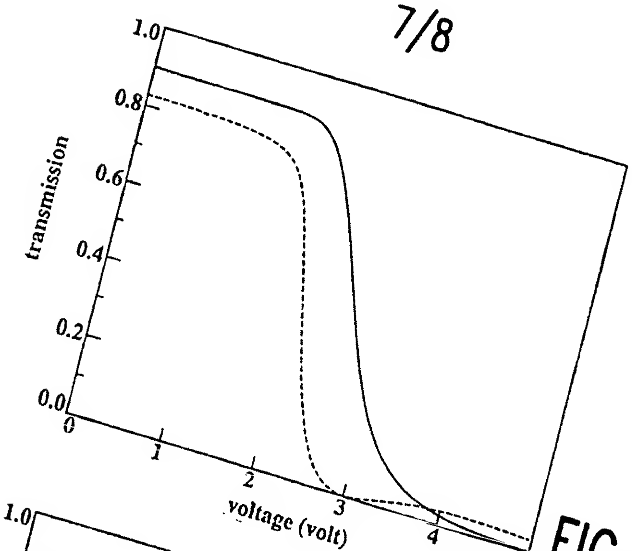


FIG. 12a

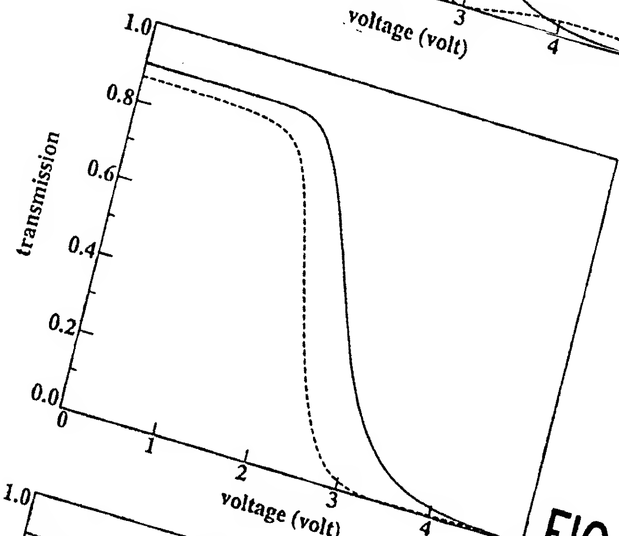


FIG. 12b

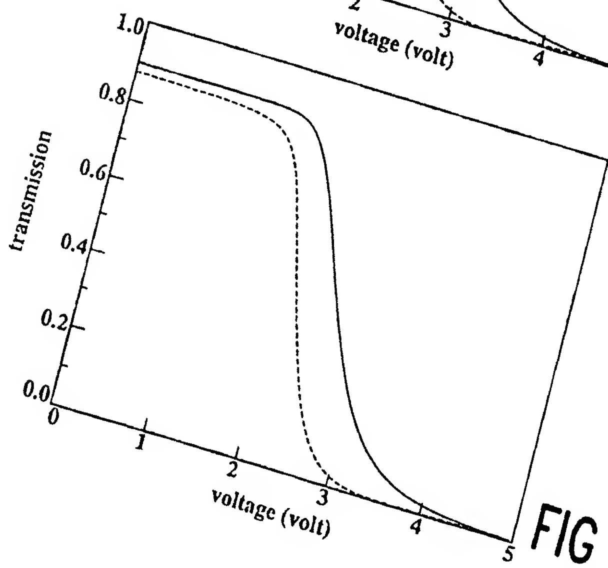
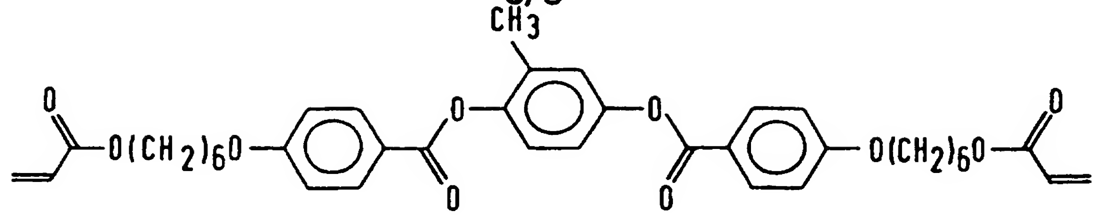
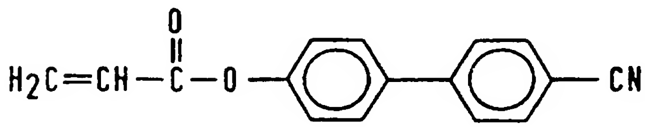


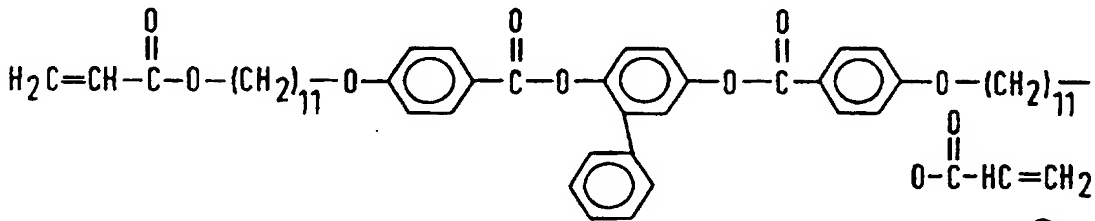
FIG 12c



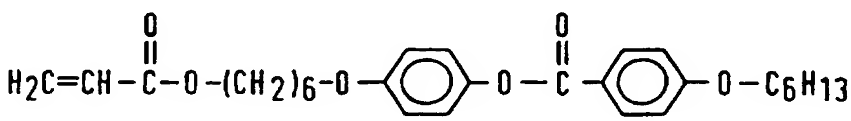
a



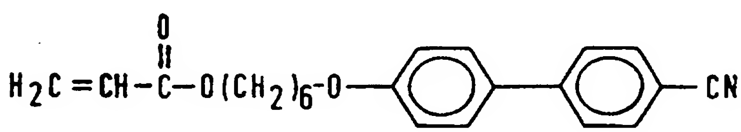
b



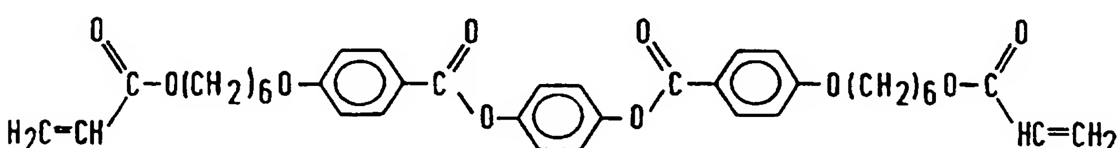
c



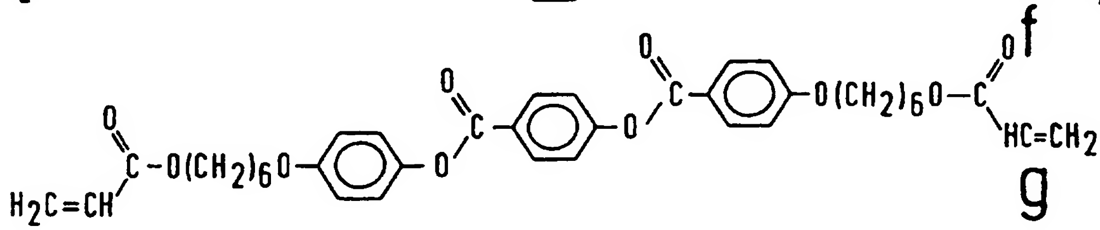
d



e



f



g

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 97/00470

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G02F 1/1335, G09F 9/35
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G02F, G09F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, CLAIMS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5237438 A (T. MIYASHITA ET AL.), 17 August 1993 (17.08.93), column 10, line 3 - column 14, line 13, figures 4,7, abstract --	1,10-12
X	US 4984874 A (T. YAMAMOTO ET AL.), 15 January 1991 (15.01.91), column 5, line 59 - column 7, line 68, figures 1,2A,2B, abstract --	1,10-12
A	US 5179458 A (T. FUKUI), 12 January 1993 (12.01.93), column 2, line 52 - column 4, line 60, figures 3,4, abstract --	1-21

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 October 1997	21 -10- 1997
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Karin Säfsten Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 97/00470

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5082353 A (K. KAWASAKI), 21 January 1992 (21.01.92), column 4, line 17 - column 5, line 3, figure 1, abstract	1-21

--

INTERNATIONAL SEARCH REPORT
Information on patent family members

01/10/97

International application No.
PCT/IB 97/00470

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5237438 A	17/08/93	EP 0512459 A	11/11/92
		JP 4330416 A	18/11/92
		JP 4330417 A	18/11/92
		JP 5019251 A	29/01/93
		JP 5061037 A	12/03/93
		JP 5061038 A	12/03/93
US 4984874 A	15/01/91	EP 0350075 A	10/01/90
		JP 2124527 A	11/05/90
US 5179458 A	12/01/93	EP 0472111 A	26/02/92
		JP 4104124 A	06/04/92
US 5082353 A	21/01/92	DE 68927332 D,T	20/03/97
		EP 0341702 A,B	15/11/89
		JP 2124526 A	11/05/90
		KR 9404711 B	27/05/94
		CN 1017169 B	24/06/92
		CN 1041624 A	25/04/90
		JP 2191490 A	27/07/90
		US 5005505 A	09/04/91